NEW FOSSIL-FUELED POWER PLANT PROCESS BASED ON LURGI PRESSURE GASIFICATION OF COAL

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I. NEW GAS TURBINE POWER PLANT USING LURGI PRESSURE GASIFICATION OF COAL

A new type power plant has been developed by the combination of Lurgi pressure gasification with a gas turbine process, which is capable of solving major problems in power plant technology.

The use of Lurgi pressure gasification of coal ahead of thermal power plants was proposed already many years ago, but the necessary process scheme could be realized only now after industrial gas turbines had been sufficiently developed and proved successful on a large scale.

Steinkohlen-Elektrizität AG (STEAG) undertook to work out a combined scheme of coal pressure gasification, gas turbine and steam power plant and to further improve this scheme in cooperation with their partners. The results were so promising that STEAG decided to realize this scheme and to place the order for the construction of a power plant integrated with coal pressure gasification for an output of 170 megawatts. The plant will be installed in the Kellermann power station at Lünen (West Germany) and is scheduled to go on stream by mid-1971. It shall serve chiefly for covering peak load requirements.

The present paper deals with this new process scheme.

II. REQUIREMENTS FOR COAL GASIFICATION WHEN USED IN GAS TURBINE PROCESSES

The commercial application of a gasification process in conjunction with power plants is new. The paper therefore describes first the relationship between the technology of gasification and the special features of the gas turbine process.

In the open cycle gas turbine process with internal combustion, which is used in the present case, fuel gas is burnt under pressure with a surplus of air, and the combustion gas is utilized as driving energy in a gas turbine. The fuel gas is generated by the gasification of coal. This means that the combustion reaction underlying all thermal power plants, namely

$$C + O_2 = CO_2 + 173,000 \text{ BTU/lb. mol}$$

is split up as follows:

a) Gasification of solid fuel, for instance, according to the simplest gasification reaction

$$C + \frac{1}{2} O_2 = CO + 51,000 \text{ BTU/lb. mol}$$

b) Combustion of the product gas in the combustion chamber of the gas turbine under pressure

$$CO + \frac{1}{2} O_2 = CO_2 + 122,000 \text{ BTU/lb. mol}$$

The total of these reactions is again the combustion formula. As the gas must be supplied under pressure, the first requirement demanded from the gasification process is:

1st Condition: Gasification under pressure.

In the gas turbine process, the same as in any other thermal power process, the difference between inlet temperature and outlet temperature of the gas during its depressurization is the measure for the heat rate. The higher the inlet temperature of the gas the higher the process efficiency. The maximum inlet temperature is limited by the service life of the blade material. It is therefore a requirement that the fuel gas burns without leaving any residue. The gas must obviously be free of solids, but gas from coal gasification contains, apart from solids, such as coal dust and fly ash, also many other impurities, such as vaporized ash, alkali and chlorine which are detrimental to the operation of gas turbines, and it further contains gaseous sulfur compounds which are not harmful to gas turbines. All these characteristics are well-known from coal combustion, and this is the reason why very high stacks are a typical feature of coal-fired power plants.

It is therefore necessary to arrange a gas purification step between gasification and gas turbine.

2nd Condition: Gas purification ahead of gas turbine combustor.

To demonstrate the special features of the combined gasification and gas turbine process, very simple schemes based on elemental carbon as fuel have been prepared (see Fig. 1). Figure 1a shows the simplest possible gasification process. In fact, attempts have been made in the past to realize this process which consists of

> Gasifier
>
> in which the coal is gasified with air under pressure. (The product gas contains 34 % Vol CO. The gas outlet temperature is 1450°C).
>
> Gas purification
>
> In view of the prevailing temperature range, gas purification can merely effect primary removal of dust while it cannot clean the gas sufficiently to reach the purity level required for the gas turbine. This step is therefore only shown in dashed lines on the diagram.

Gasification is followed by the gas turbine process which is shown as an open-cycle gas turbine process without heat recovery, and which shall merely serve for comparison. It consists of

> Combustor
>
> in which the gas is burnt and the maximum gas turbine inlet temperature is adjusted by the addition of air. (An inlet temperature of 820°C can already be realized nowadays).
>
> Gas turbine
>
> with air compressor and generator.
>
> Waste heat recovery
>
> which is necessary for economic operation of the gas turbine process.
>
> The example shows that the exhaust gas quantity is 6 times greater compared with the combustion in conventional steam boilers. Besides, the exhaust gas

temperature at the gas turbine outlet of 394°C is still rather high. The resulting heat loss in the exhaust gas represents basically the same problem as the heat loss by condensation of the steam in steam power plants.

The simplest coal-based gas turbine process presented in the above example already demonstrates the problems which require solution for the application and improvement of the scheme.

First of all, the gas must be available under conditions which allow proper purification. The gas has to be cooled down and subjected to intensive washing whereby the solids are reduced to less than 1.5 ppm and the alkali originating from the ash is removed. This satisfies the requirements demanded by the gas turbines. Hence, the second condition has to be supplemented:

2nd Condition - Supplemental requirements:
Purification of gas by water wash
ahead of gas turbine.

This water wash is a combination of a quencher and a washer. The gas is cooled by water evaporation whereby part of the sensible heat is lost. There are several possibilities for keeping this loss at a minimum.

The most obvious possibility is to provide a waste heat boiler ahead of the washer, as it is done, for instance, in oil gasification (partial oxydation), or to transfer the sensible heat of the gas to the compressed air for the gas turbine process in a heat exchanger. However, experience with coal-fired steam boilers shows that the heat transfer surfaces tend to foul up rapidly. In conjunction with pressure gasification, the conditions are even more difficult so that this possibility can hardly be realized technically.

Another way would be to utilize the high proportion of sensible heat of the gas for endothermic gasification reactions according to the following equation:

$$C + H_2O = CO + H_2 - 52,800 \text{ BTU/lb. mol}$$

This alternative is shown in Fig. 1b. Methane formation which is involved also in pressure gasification has been neglected for reasons of simplification.

In the example of carbon gasification, the gas outlet temperature is reduced to 790 ^{o}C by the addition of steam to the gasification agent, and the loss of sensible heat on gas cooling is decreased accordingly.

Consequently, the next requirement for the gasification process is:

3rd Condition: Addition of steam to gasification agent.

To achieve the theoretical equilibrium temperature during practical operation and to ensure smooth progress of gasification at this relatively low temperature, countercurrent flow of coal and gasification agent is a necessity which can best be performed in a fixed bed. Fixed-bed gasification moreover meets the requirements regarding reaction kinetics. Another prerequisite for the gasification process therefore is:

4th Condition: Countercurrent gasification.

This requirement is even still more important when considering the gasification of coal instead of elemental carbon gasification, for the following two reasons:

Firstly, complete incineration is achieved only during countercurrent operation. Secondly, high volatile coal, for example, contains only about 65 % fixed carbon related to the d.a.f. coal, the balance being volatile matter which can be recovered by degasification during countercurrent operation and which constitutes 30 % of the heat content of the product gas.

In Fig. 1b the gas washing step is arranged downstream of carbon gasification with air and steam. Cooling down of the gas by quenching causes a loss of 15 % of the heat brought in with the fuel. This loss is only 8 - 10 % during the gasification of coal. This heat loss is not higher than in a coal-fired steam boiler, but it is still considerable.

It shall now be demonstrated that the energy loss in this gas production scheme is in reality much lower when considering the overall energy balance. To prove this, each of the two gasification processes is followed by the same simple gas turbine process.

Saturation of the gas with steam in the quencher causes an increase in the gas volume. Corresponding to this additional gas volume, the consumption of secondary air to the combustor decreases, which means that less energy is needed for air compression and that the net output of the gas turbine increases accordingly. In this connection it is further of advantage that the enthalpies and the enthalpy difference of the steam at a given temperature respectively temperature difference are greater than those of the air, so that the heat duty of the steam for a given pressure drop is higher compared with air.

A comparison between the two schemes proves this. The net output of the gas turbine is about the same in both cases. Merely the amount of sensible heat in the waste heat is less in the scheme "Gasification with steam + Gas Wash". This disadvantage can be tolerated because the exergetic value of the waste heat is relatively low, and because the complete purification of the gas effected by the wash process permits adjustment of the high gas temperature necessary for a good thermal efficiency.

Finally, the question of gas desulphurization should be considered which has been neglected so far as it is not of primary importance for the operation of the gas turbine process proper. When all other impurities have been removed from the gas, the presence of gaseous sulfur has, according to the gas turbine manufacturers, no adverse effect on the operation of the gas turbines. But the higher dew point of the fuel gas due to the presence of SO_2 and SO_3 renders waste heat recovery more difficult; this is known from conventional steam power plants.

However, the chief problem is that of air pollution. If it is possible to find technically and economically feasible solutions, this would be a real step forward.

The combination of pressure gasification with thermal power processes is a suitable way for gas desulfurization because the sulfur compounds, chiefly H_2S with a little bit of organic sulfur but no SO_2 are present in a pressurised fuel gas having an effective volume of only 1.5 % of the volume of the gas from an atmospheric combustion process. This H_2S under pressure can easily be removed by absorption in conventional wash processes and converted to marketable products, namely elemental sulfur or sulfuric acid.

The condition of the gas must of course meet the requirements for the application of the wash process for sulfur removal. These are pressures above 140 psi, temperatures of 20 - 180°C and a sufficient concentration of the component to be removed. Consequently, there is another requirement for the gasification process:

5th Condition: The condition of the gas must allow the use of a wash process.

The process scheme described meets these requirements. For further particulars reference is made to Chapter 3.6. This concludes the general considerations which have demonstrated that coal gasification can be efficiently combined with a gas turbine process and that conventional methods can be used for fuel gas desulfurization. The various requirements demanded from the gas production process are summarized below:

1st Condition:	Gasification under pressure
2nd Condition:	Gas purification ahead of gas turbine by water wash
3rd Condition:	Addition of steam to gasification agent
4th Condition:	Countercurrent gasification
5th Condition:	The condition of the gas must allow the use of a wash process.

III. DESCRIPTION OF GASIFICATION PROCESS

3.1 Choice of Gasification Process

Apart from the five process requirements for coal gasification in conjunction with gas turbine power plants, which were examined in Chapter 2., there are three further requirements which concern the economics and which have to be considered when selecting the gasification process.

The investment cost for the gasification plant must not be higher than that for conventional processes which are based on the direct burning of coal.

6th Condition: The investment cost must be competitive with other processes.

Another obvious requirement is:

7th Condition: The plant must yield a profit.

Final requirement for the realization of the scheme:

8th Condition: The process must have proved its merits in practice.

A study of the available gasification processes has shown that LURGI pressure gasification meets the above requirements. A brief survey is given first on the application and technical reliability of LURGI pressure gasification, followed by a detailed description of the process.

3.2 Previous Application of LURGI pressure gasification Process

LURGI pressure gasification is a coal gasification process which has so far been applied on a commercial scale for the manufacture of town gas and synthesis gas. The process was first developed in 1933. The initial pilot plant was build in 1936 at Hirschfelde (Central Germany). This plant is still in operation for town gas production today after 33 years.

In 1938 the construction of commercial plants began. Since then, a total of 58 gasifier units for 12 plants have been built by LURGI in all parts of the world. These plants produce the following gas rates:

265 million scf/d of town gas, and
230 million scf/d of synthesis gas.

As will be seen from Fig. 2 these plants handled 40 million tons of coal up to 1969, the output of ash being 8 million tons.

The commercial plants process lignite, sub-bituminous coal and anthracite. Ash contents of up to 35 % do not create any difficulties. When producing town gas or synthesis gas, oxygen and steam are used as gasification agent.

When applied to the production of fuel gas for gas turbine power plants, air and steam can be used as gasification agent. This simplifies the arrangement and operating conditions of the plants considerably compared with town gas and synthesis gas plants.

3.3 General Outline of Scheme

A simplified flow diagram of the STEAG plant is presented in Fig. 3. The desulfurization unit is shown in dashed lines because this unit is not installed for the present due to the low sulfur content of the feed coal.

Fig. 4 shows the arrangement of the gasification plant within the power plant scheme.

The coal is gasified in the LURGI pressure gasifier with air and steam under a pressure of, say, 300 psi. The gasification pressure may be higher or lower.

The coal is fed via a lock hopper to the gasifier where it is gasified completely in countercurrent with the gasification agent. Ash is removed via an ash lock hopper. The producer gas is washed in a scrubbing cooler and saturator and is then available for the gas turbine process. The gas is saturated with steam and free of solids.

3.4 The Gasification Process

The gasification process is illustrated in Fig. 5. The gasification agent consisting of air and steam enters the gasifier through slots in the rotary grate. It flows through the ash zone arranged above the rotary grate and is then distributed over the cross-sectional area of the gasifier shaft.

It then enters the combustion zone which in the pressure gasifier is relatively narrow. Its height is about 5 times the diameter of the coal grains. This means that the residence time of the coal and the ash in the combustion zone is short.

The ash is removed continuously via the rotary grate. It is incinerated substantially completely and is cooled to about 500^{o} C by the gasification agent. The temperature in the combustion zone is controlled by the rate of steam addition which is about 0,6 scf steam/scf air during gasification with air. In this connection it should be noted that the temperature in the combustion zone is much lower than the theoretical figure obtained from the heat balance and under the assumption of complete combustion. The figure shows the difference between maximum temperature, which is only a fictitious value, and the real temperature. The reason for this substantial temperature difference is that, parallel to the combustion reactions, the initial gasification reactions proceed already in the combustion zone. These endothermic reactions reduce the temperature to a level of between 1000 and 1200°C, as experience has shown. Inspite of this relatively low temperature a virtually complete incineration of the ash is achieved.

The combustion gas flows upwards into the gasification zone. Its sensible heat is utilized to complete the endothermic gasification reactions which proceed according to the following equations:

1.	Boudouard reaction	$C + CO_2 \rightleftharpoons 2\,CO$	
2.	Water gas reaction	$CO + H_2O \rightleftharpoons CO_2 + H_2$	
3.	Methane formation	$C + 2\,H_2 \rightleftharpoons CH_4$	

Parallel to gasification, devolatilization of the fuel takes place. The proportion of devolatilization gas is considerable and amounts to about 30 % related to the N_2-free gas.

Depending on the reactivity of the fuel, the reactions freeze at 720 - 850°C. This is the reaction end temperature, at which a gas equilibrium is established which determines the gas composition.

Fig. 5 shows that the application of the countercurrent principle allows the utilization of the sensible heat of the gas for coal drying and preheating. Consequently, the gas outlet temperature is relatively low. It is about 500°C when processing sub-bituminous coal, and about 300° C when gasifying lignite.

At the temperature the gas leaves the gasifier. The dry crude gas has about the following composition:

CO_2	14 % vol.
CO	16 % vol.
H_2	25 % vol.
CH_4	5 % vol.
N_2	40 % vol.
	100 % vol.

This gas further contains:

Steam from coal moisture and undecomposed steam,

Tar, oil and naphtha in vaporous form,

Other carbonization products of the coal, such as phenols, fatty acid, NH_3,

The sulfur from the coal is present in the gas as 95 % H_2S and 5 % organic sulfur. Very little coal dust is also present.

The gasification efficiency at the gasifier outlet is about 95 %, the losses comprising 1 - 2 % losses due to unburnt matter in the ash and 3 - 4 % heat losses.

The gas is available under pressure.

3.5 Purification of Gas to Gas Turbine Purity

As the hot gas leaving the gasifier still contains little coal dust (0.01 - maximum 0.5 % wt. of the coal input) and traces of alkali and sometimes also chlorine, it must be subjected to purification treatment to make it suitable for the gas turbine process.

Pressure gasification affords complete removal of solids from the gas by quenching and washing with hot tar-containing water which is circulated. The investment cost for the required equipment is low (see Fig. 4). Cooling of the gas to saturation temperature of, say 160 °C causes a loss in efficiency which can, however, be tolerated because it provides on the other hand for the gas purity which is required for undisturbed continuous operation of the gas turbine.

As higher-boiling tar fractions are condensed during cooling, the circulating wash water contains tar to which the traces of coal dust are bonded. A partial stream of the circulating water is withdrawn from the saturator and routed to a separator. The precipitated mixture of tar and dust is returned from the separator to the gasifier for cracking and gasification.

The scrubbing cooler/saturator system also removes other impurities, such as alkali and chlorines which would be detrimental to gas turbine operation. The carbonisation products from the coal, such as tar oil, naphtha, phenols, ammonia, etc. which are still present in the gas can be burnt completely. Steam saturation increases the steam proportion to 0.5 scf H_2O/scf dry gas.

Saturation with steam results in an increase in the volume of the gas. The volume of the wet gas at the saturator outlet (before entering the combustor of the gas turbine) is about 1.5 times the volume of the dry gas. While the cooling of the gas by saturation with steam causes a loss of sensible heat resulting in a reduction of the gasification efficiency, this loss is compensated in part by the increase in the gas volume which means a higher energy output from the gas turbine. This point was discussed previously.

3.6 Gas Desulfurization

The gas leaving the scrubber/saturator system is free of solids, alkali and chlorine and is suitable for the gas turbine. It still contains gaseous sulfur compounds which are not harmful to gas turbine operation but which create air pollution problems as they are emitted as SO_2/SO_3. The new and more stringent air pollution regulations require removal of the sulfur from the gas. The efforts to meet this goal in conventional steam power plants have not been successful so far, because the problems in a combustion process under atmospheric pressure are difficult for the following reasons:

a) the volume of the flue gas is relatively large,

b) the flue gas contains fly ash,

c) the flue gas is available at atmospheric pressure and temperatures of 120 - 200°C.

In the scheme using pressure gasification the problems are far less complicated and the above mentioned disadvantages are eliminated.

During pressure gasification, the coal sulfur is composed of:

90 % H_2S
5 % organic S
5 % ash sulfur

The gaseous sulfur compounds can be removed by a wash process under pressure. It is of importance that other gas consituents are not lost during the wash process. Washing with ammoniacal liquor is particulary suitable for selective removal. In this connection it is an advantage that the coal nitrogen appears in the pressure gasification gas as ammonia which means that the wash solution is a product from coal gasification. The wash system is illustrated in Fig. 6.

H_2S removal proceeds according to the following reversible reaction:

$$(1) \qquad NH_3 + H_2O + H_2S \rightleftharpoons NH_4HS + H_2O$$

The wash process operates under pressure and at gas temperatures of say, 40 °C. The fat solution is regenerated by flashing and heating. The H_2S gas from the regenerator is available as feed for the Claus process to recover sulfur or for wet contact catalysis to recover directly sulfuric acid.

The presence of CO_2 in the gas renders the wash process more difficult. CO_2 is equally removed with ammoniacal liquor according to the following equations:

$$(2a) \qquad CO_2 + H_2O \rightleftharpoons H_2CO_3$$

$$(2b) \qquad H_2CO_3 + NH_4OH \rightleftharpoons NH_4HCO_3 + H_2O.$$

In spite of the high CO_2 partial pressure of the crude gas it is possible to remove H_2S selectively because CO_2 removal according to equations 2a) and 2b) proceeds relatively slowly. A technically feasible solution is a short residence time wash process where the gas is only in temporary contact with the wash solution. This short residence time wash process shall ensure that reaction 2a) and 2b) are incomplete while reaction 1) proceeds to the end.

The following further problem has to be considered for the realization of the proposed wash process.

The pressure gasification gas is saturated with steam at 140 - 160°C which means that it contains a considerable amount of sensible heat. As low temperatures are more favourable for the wash process and for the preferential completion of reaction (1) versus reaction (2), a cooler / saturator system has been incorporated which removes the sensible heat from the gas with circulation water in a cooler and which returns the sensible heat to the gas in a saturator downstream of the H_2S removal unit.

Cost of H_2S removal

Expenditure

a)	Capital charges for the scheme presented in Fig. 6 including Claus unit (15 % depreciation and interest, 8000 h/a):	44 %
b)	Heat losses:	10 %
c)	Heat requirements for H_2S removal (calory price of fuel = 44 cents MM BTU):	24 %
d)	Electricity and cooling water:	12 %
e)	Labour + maintenance:	10 %
		100 %
	=	0.565 mills/kwh

Proceeds

a) The coal sulfur is, for example, recovered as sulfur in a Claus kiln. At 3.4 % wt. S in the daf coal and a sulfur price of $ 24,60 per sh. ton, the credit is

16.5 lb. S/MW x 1.23 UScents/lb. S = 0.202 mills/kwh

b) Credit for steam from Claus unit

$$\frac{2.75 \text{ lb. steam}}{1 \text{ MW}} \times 0.1 \text{ UScent/lb.} = 0.027 \text{ mills/kwh}$$

0.229 mills/kwh

Consequently, the cost of gas desulfurization is

0.565 mills/kwh - 0.229 mills/kwh = 0.336 mills/kwh

which has to be added to the power generation cost.

IV. APPLICATION OF NEW PROCESS USING THE LÜNEN POWER PLANT AS AN EXAMPLE

Following the description of gas production and gas purification, the process scheme of the Kellermann Power Plant of STEAG at Lünen will now be explained in detail.

4.1 Process Scheme and Design Features

The gas turbine power plant integrated with pressure gasification of coal will generate 165 megawatts at a thermal efficiency of 36 %. It shall be used to cover peak requirements for which it is well suitable because of the little time needed to start-up the gas production unit and the gas turbine. The power plant consists of the following units:

1. Gas production to handle 76 sh.tons/hr of coal with a net calorific value of 10,450 BTU/lb. and to produce 6,800,000 scf/hr. dry fuel gas.

1.1 5 LURGI pressure gasifiers - working pressure 300 psig
cross-sectional area: 30 ft^2/gasifier

1.2 Tar recycling

1.3 Gas wash

2. Expansion turbine to reduce the pressure of the producer gas from 290 to 140 psig.

2.1 1 gas heater

2.2 1 expansion turbine with compressor for the gasification air.

3. Gas turbine plant

3.1 Double combustor with

3.1.1 Gas-fired burners where the gas is burnt at an almost stoichiometric ratio.

3.1.2 Steam boiler, consisting of vaporizer and superheater. The hourly output of steam is 750,000 lb. at 1,900 psig and 525 °C.

3.1.3 Little air is added to the lower section to adjust the temperature of the combustion gases to the level permissible for the gas turbine.

3.2 Gas turbine with air compressor.

3.2.1 The gas turbine is a SIEMENS single-shaft gas turbine.

Inlet pressure		137 psig
Inlet temperature		820 °C
Output	roughly	175 MW

3.2.2 Air compressor directly coupled to the gas turbine.

3.3 Generator.

The net output of the gas turbine set is 74 MW

4. Utilization of Waste Heat.

The sensible heat contained in the combustion gas when leaving the gas turbine is utilized for two-stage preheating of the feed water whereby the temperature of the exhaust gas is reduced to 168 °C.

As the Lünen plant does not include a desulfurization step, the increase in dew point due to the SO_2/SO_3 content in the combustion gas had to be considered for waste heat utilization.

5. Steam turbine

5.1 The turbine is a condensing steam turbine with steam extraction for gasification and for feed water preheating.

5.2 Generator with an output of 98 MW.

Other typical features of the new scheme which are incorporated in the STEAG plant but which were not mentioned in the preceding chapters:

Expansion turbine and

integration of gas turbine process with steam power process.

The expansion turbine is arranged between gas production unit and combustor. The economic pressure level for gasification is above 300 psig, while with the prevailing ratio of the flow through the gas turbine to the flow through the air compressor the economic gas turbine feed pressure is about 140 psig. Consequently, the expansion of the gas in a turbine is a suitable proposition.

The incorporation of an expansion turbine is very economical in the present case because the ratio of the gas flow through the expansion turbine to the air flow through the compressor is

$$\frac{3 \text{ scf gas}}{1 \text{ scf air} + 0.5 \text{ scf steam}}$$

The output of gas volume from the gasification process is twice the quantity of the input gasification agent. Related to air only, three times as much gas is expanded as gasification air is compressed.

The increase in volume is partly due to the H_2O introduced into the gas during quenching, which was described in the preceding chapters. Moreover, the increase in volume takes place during gasification and devolatilization of the coal.

At an input of		1.0 scf gasification air
	+	0.5 scf gasification steam
		1.5 scf

the gas output is

by gasification	1.85 scf gas
by devolatilization (including coal drying)	0.25 scf gas
by quenching with water	0.90 scf steam
	3.00 scf

This increased volume can be utilized during pressure gasification by the incorporation of an expansion turbine whereby additional energy is provided.

This advantage which is gained from the combination of gas turbine process with gasification or reforming has been utilized in the present project only to a limited extent. The capacity of the expansion turbine could have been increased by further increasing the inlet temperature from 200 to 400°C and the pressure drop from 280 / 140 psig to 420 / 140 psig so that an extra 7 - 8 MW useful energy would be obtained. This would increase the thermal efficiency of the overall process from 36 to 37.5 %.

Another characteristic feature of the power process applied in the Lünen plant is the pressurized steam boiler. The VELOX boiler is known as boiler operating under pressure. The concept used in the present plant has, however, nothing in common with the principle of the VELOX boiler. In the VELOX boiler, increased flue gas velocities of 600 ft/sec are applied to improve the heat transfer coefficient and to thus reduce the boiler heating area. The pressure drop in a VELOX boiler is up to 45 psig.

The present scheme uses a pressurized steam boiler which operates at 140 psig gas pressure and where the ratio of pressure drop to working pressure of 0.2×10^{-2} is not higher than in normal steam boilers or heat exchangers. Initial examinations into the possibilities and economics of this pressure steam boiler were made by Prof. Drawe and Prof. Zinzen at the Technical University of Berlin in 1948. The results were very positive, but the status of technique at the time did not permit the realization of these ideas. This concept was taken up for the present project under consideration of the following major aspects:

1. By arranging a steam generator between combustor, where stoichiometric combustion takes place, and gas turbine, it is possible to remove sufficient heat from the combustion gas so that the temperature of the combustion gas can be adjusted to the level required for the gas turbine, say, 820°C. As no additional air is required, the net output of the gas turbine set increases.

2. During stoichiometric combustion, i.e. without the use of additional air for cooling the combustion gases, the waste gas rate is reduced to the minimum level possible, whereby the loss of waste gas, which is rather considerable in conventional gas turbine process, is also cut down.

3. The combination of steam power process with gas turbine process enables economic utilization of the waste heat from the gas turbine process for feed water preheating.

4. Owing to the better heat transfer coefficients, the pressure steam boiler requires a smaller heating area which makes it less costly compared with conventional steam boilers.

Hence, the integration of the thermal power process in the gas turbine process improves the efficiency and cuts down the investment costs.

4.2 Technical Data and Investment Costs

The following is a summary of the major technical data of the pressure gasification / gas turbine power plant at Lünen based on the information received from STEAG.

Technical Data of STEAG Power Plant

Coal consumption	76 sh. tons/hr (n. c. v. of coal 10,450 BTU/lb.) equal to 1,580 x 10^6 BTU/hr
Output of gas turbine	74 MW
Output of steam turbine	96 MW
	170 MW
Power required for drivers	5 MW
	165 MW
Thermal efficiency	36 %
Total heat demand	9400 BTU/kwh
Air throughput	16.5 lb./kwh
Steam consumption	4.5 lb./kwh
Combustion gas rate	18.5 lb./kwh
Cooling water consumption (gradient 8.8 °C)	25.6 gal/kwh
Hence:	
Consumption of make-up water	0.465 gal/kwh
+ feed water	0.169 gal/kwh
	0.634 gal/kwh

Space Requirements

The space required for this power plant (excluding cooling tower) is only

$$175 \text{ ft} \times 160 \text{ ft} = 28,000 \text{ ft}^2$$

The built-around volumetric space is 1,340,000 ft^3.

Investment Costs

The investment costs of the Lünen power plant are 15 - 20 % lower compared with conventional power plants of same size. The capital expenditure based on the prices in 1968 and excluding gas desulfurization amounts to roughly

$ 90,--/kw

This figure includes $ 19,--/kw for gas production.

The construction period for such power plants is shorter than for conventional power plants as the gasifiers, pressure steam boilers, etc. are completely fabricated in the manufacturers' works so that erection includes only the lifting in position of the equipment and the installation of interconnecting pipework.

V. APPLICATIONS AND FUTURE DEVELOPMENTS

The example of the new STEAG power plant at Lünen is only one of the possible applications and designs. It uses process and equipment which have already proved their technical reliability on a commercial scale. It is therefore merely a first step in this new direction. Meanwhile, STEAG and LURGI have explored the possibility of how this new power plant scheme could be improved further and what other process combinations could be chosen. A brief report is given about these future developments to conclude this paper.

The efficiency of the overall scheme could be improved by introducing the following measures, amongst others:

1. In the gas production process: Increasing the capacity of the expansion turbine by preheating the gas to a higher temperature prior to expansion and by the

application of a higher gasification pressure.

2. In the gas turbine process: Increasing the gas turbine inlet temperature.

3. In the thermal power process: Application of intermediate superheating.

Recent investigations carried out by STEAG have shown that the thermal efficiency will increase to 40.5 % by intermediate superheating of the steam, and to 42-45 % by increasing the gas turbine inlet temperature.

The trend in gas turbine manufacturing towards larger scale units will permit the construction of power plants of the present type with larger unit capacities, which will reduce the specific investment costs.

The combination of gas turbine process with steam power process has been chosen because this combination improves the efficiency of the overall scheme due to the lower air compressor capacity. The same effect could be achieved by utilizing the waste heat from the turbine exhaust gas for steam saturation of combustion and gasification air.

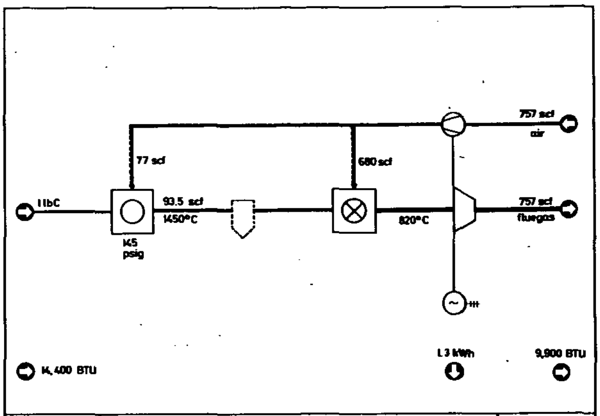
There might be cases where owing to shortage of water the combination with a steam power process cannot be realized. In the combination of pressure gasification with gas turbine process only, water consumption can be reduced to 0.1 gal/kwh which is only 10 % of the water requirements for conventional thermal power processes.

The prototype of the new power plant at Lünen shows that the combination of pressure gasification with gas turbine process requires only a minimum of time for start-up which is the reason why STEAG use this plant mainly to cover peak load requirements. As the coal can be stored and the investment costs for the power plant and in particular for gas production are relatively low, the gas-from-coal power plant can supply the peak gas load while nuclear power plants and natural gas power plants supply the basic load.

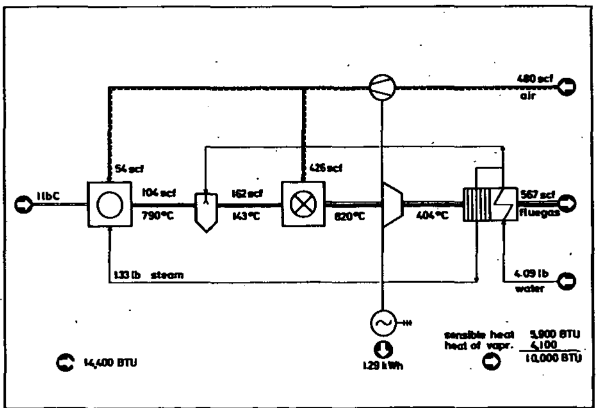
Another interesting aspect is that the gas turbine can also handle other gases, such as natural gas, coke-oven gas, etc. As the coal pressure gasification process can very well cope with load variations, the possibility of mixed operation exists.

In summing up, the following advantages of the new power plant process can be stated·

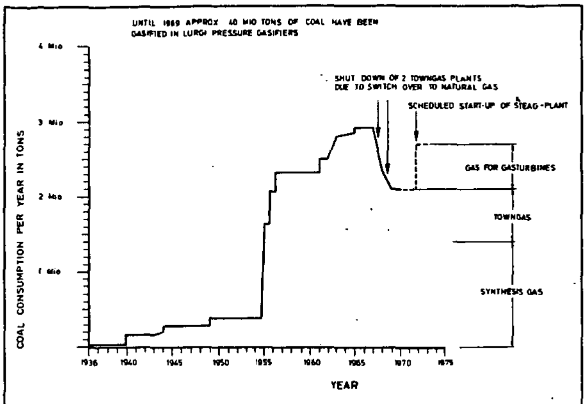
- High efficiency and low investment costs.
- Gas desulfurization can be accomplished economically so that air pollution problems are eliminated.
- It can readily cope with special conditions, such as shortage of water, peak load demand, etc.
- It offers better possibilities for further improvement than the conventional thermal power process.



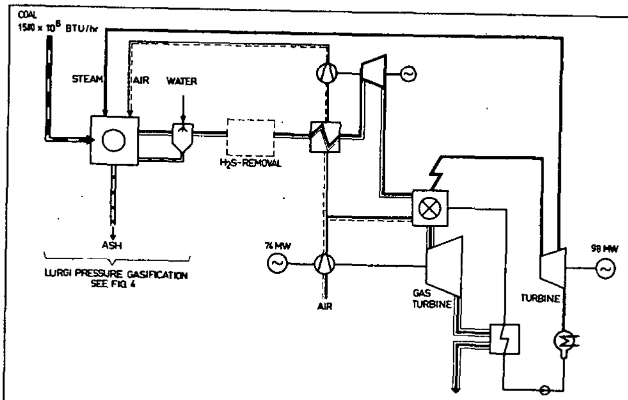
(LURGI) GASIFICATION OF CARBON WITH AIR FIG. 1a



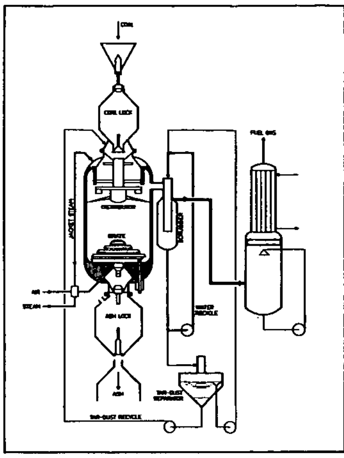
(LURGI) GASIFICATION OF CARBON WITH AIR AND STEAM FIG. 1b



LURGI | YEARLY COAL CONSUMPTION IN LURGI PRESSURE GASIFICATION PLANTS | FIG. 2

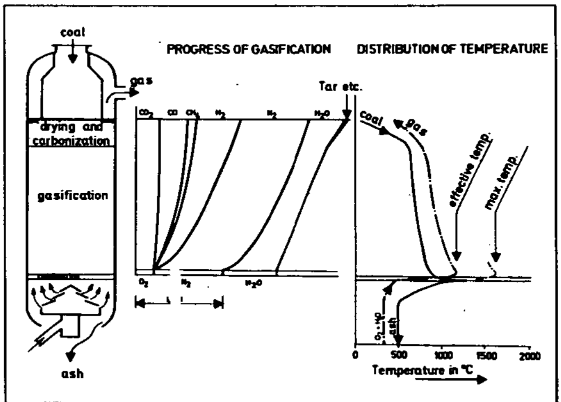


COMBINATION OF GASIFICATION WITH GAS TURBINE POWER PLANT | FIG. 3



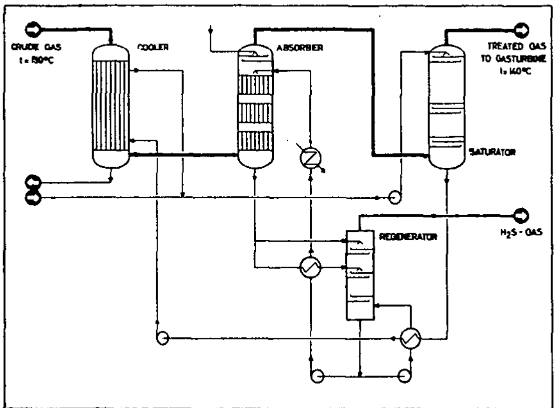
LURGI PRESSURE GASIFICATION FOR FUEL GAS PRODUCTION

FIG. 4



PERFORMANCE OF GASIFICATION IN A PRESSURE GASIFIER

FIG. 5



LURGI

H_2S - REMOVAL

FIG. 6